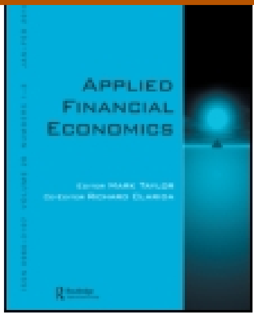

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An empirical study of Taiwan's bond market based on the nonlinear dynamic model

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This article examines long-run dynamic adjustments of the term structure of interest rates using Taiwan government bond interest with different maturities. This permits threshold and momentum-threshold adjustments to test for asymmetry in unit roots and cointegration. More specifically, we employ nonlinear methodology to investigate whether the term structure of interest rates is consistent with the expectation theory. The results support the expectation theory in the case of the term structure of interest rates with dynamic adjustment. Furthermore, we find solid evidence of the asymmetric price transmission effect among bonds with different maturities in both the short and long run, and we employ the asymmetry error-correction model to successfully capture dynamic adjustments of interest rates.

I. Introduction

Since state-of-the-art trading systems and sophisticated financial products were first integrated into Taiwan's bond market in 2000, the volume of trade in that market has escalated substantially. The daily trading volume has, in fact, far surpassed trading turnover on the Taiwan Stock Market (TSE). However, the fact that the Taiwan bond market is simply confined to such institutions as banks, securities and insurance companies often means that it is ignored by the public. In essence, since the interest rate is one of the major factors influencing the prices of financial instruments in financial markets, fluctuations in interest rates in the bond market are regarded as the leading indicator of trends in the overall interest rate. Importantly, this implies that for individual investors, enterprises and financial institutions alike, having a good understanding of the implications of short- and long-term changes in interest rates can help reduce business risks.

The term structure of interest rates refers to the relationships between the yield rates of bonds with different maturities. In accordance with the term structure of interest rates, the theoretical price of a bond can be determined at any place and any time, and while this can reduce risks in an investment portfolio, it can also serve as a tool to evaluate investment performance. In addition, the term structure of interest rates reflects all market participants' future expectations with respect to interest rates and inflation rates. As far as policy-makers are concerned, the term structure of interest rates can be invaluable for the analysis and formulation of monetary policy.

Fisher (1930) was the first to propose the expectation theory which argues that investors' expectations about future spot interest rates affect current

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long-term interest rates. The theory was later developed by Lutz (1940), who claimed that the relations among yields with different maturities were subject to investors' expectations about future interest rates. Since then, the expectation theory has come to play an important role in empirical studies on the term structure of interest rates. In essence, the theory holds that current long-term interest rates are equivalent to future expected short-term interest rates and premiums which reflect liquidity and preference at the time of maturity. Using the variance bound test, Shiller (1979) determined that the expectation theory was not consistent with the hypothesis that the long-term interest rate is the mean value of the expected short-term interest rates and that there are few fluctuations. Shiller also reported that the expectation theory is not applicable when the yield rates of long-term bonds fluctuate more than the interest rates of short-term bonds. Campbell and Shiller (1987) later put forth the view that the necessary condition for the term structure of interest rates to comply with the expectation theory is for them to be cointegrated among long-term and short-term interest rates. That is, spreads on the yield rates in each period cannot be characterized by a unit root when there is long-term equilibrium. In most studies using unit root tests and cointegration (Mankiw and Miron, 1986; Campbell and Shiller, 1987; Hardouvelis, 1988), it is hypothesized that there is linear adjustment, but the empirical results from those studies failed to support the expectation theory. Those researchers claimed that, not taking time-varying premiums into account in the regression formula accounted for the failure to forecast future interest rates using spread. Mankiw and Miron (1986) and Hardouvelis (1988) held that changes in the expected future short-term interest rate could be forecast using spread as a result of structural shifts in monetary policy. Balke and Fomby (1997), for example, found that short-term and long-term interest rates in the United States are subject to nonlinear asymmetrical adjustments; they also pointed out that when variables undergo asymmetric adjustments, the traditional linear cointegration model lacks power and generates errors in estimations.

Nevertheless, a growing number of studies have shown the nonlinear asymmetrical adjustments to the time sequence of many global variables, such as the inflation rate, stock price index and the effective exchange rate (Serletis and Gogas, 2000; Abdulai, 2002; Teresa and Barry, 2003; Khadaroo, 2005). Contrary to the traditional view that variables are susceptible to linear adjustment (Engle and Granger, 1987), Tong (1983) employed the Threshold Autoregressive model (TAR) to examine patterns of asymmetry among variables, and Enders and Granger (1998), as well as Caner and Hansen (2001) have utilized the Momentum-Threshold Autoregressive model (M-TAR) to explain the phenomenon of asymmetric adjustment of variables, as characterized by increments or decrements. Enders and Granger (1998) spotted inadequacies with respect to test power with the use of traditional linear unit-root tests and cointegration tests when economic variables experience asymmetric adjustment. In related studies on the term structure of interest rates, Rudebusch (1995) observed asymmetry in the probabilities of increments and decrements in yield curves. In applying the M-TAR, Enders and Granger (1998) and Enders and Siklos (2001) have determined that when fluctuations in long-term interest rates are greater than those in short-term interest rates, the interest rates are restored to their original equilibrium, i.e. there is nonlinear long-term cointegration, at the rate of asymmetric adjustment.

In view of the above, the objectives of this empirical research are threefold. The first purpose is to analyse adjustments to the spreads of interest rates, and using the dynamic asymmetrical model, to explain the expectation theory as it applies to the term structure of interest rates in Taiwan's bond market. It is worth noting that previous research on the term structure of interest rates in Taiwan focused on the empirical study of interest rates in Commercial Paper (CP), as in the case of Shen (1993), Chuang and Duan (1996) as well as Lin *et al.* (1998). CP is a short-term money market tool with a maximum term of 360 days. Using the interest rate of CP as a research target is quite suitable for research on the short-term structure of interest rates. In those studies on CP, the research target was the short-term part of the interest rate curve. In its analysis of Taiwan's bond market, the present study supplements those earlier research findings with data on the long-term part of the interest rate curve. The second purpose of this study is to explore the term structure of long-term interest rates in Taiwan's bond market by considering the unique trading characteristics of that market. Enders and Granger (1998) and, more recently, Kuo and Enders (2004) have, respectively found evidence of nonlinear dynamic adjustments of the spreads of interest rates in the United States and Japan. The third purpose of this study is to adopt the TAR and M-TAR to explore whether spreads show asymmetrical adjustment in the long-term balanced Taiwan bond market.

The remainder of this article is divided into five sections. The next section provides a brief discussion on the expectation theory and how it applies to the term structure of interest rates and cointegration, while Section III estimates the nonlinear term structure of interest rates based on asymmetrical tests. Section IV briefly explains some possible reasons for asymmetrical adjustments to the term structure of interest rates in Taiwan, and Section V describes the characteristics of the data, summarizes the empirical results and presents some implications that emerge from this study. Finally, Section VI highlights the conclusions we draw.

II. Expectation Theory and Cointegration

Based on the rational expectation hypothesis, if an investor is risk-neutral, then the expected excess return on bonds is equal to the instantaneous interest rate; if an investor is risk averse, then he obtains the return on the premium in addition to the return on the instantaneous interest rate. Hall *et al.* (1992) expressed the expectation theory as follows:

$$R(n,t) = \frac{1}{n}\sum_{i=1}^{n} E_t R(t+i-1) + L(n,t) \qquad (1)$$

where $R(n,t)$ refers to the yield to maturity on a k period pure discount; E_t represents rational expectations based on information obtainable at point t and $L(n,t)$ is the term premium and indicates the risk premium of a long-term bond obtainable at point t. In the risk-neutral hypothesis, $L(n,t)$ is zero. Campbell and Shiller (1987) maintained that the expectation theory applies to the term structure of interest rates and that spread can be used to predict interest rates, which is the equivalent of saying that the term premium is fixed (or stationary).

Suppose the yield rate of bonds shows $I(1)$ status in the time sequence and that this means that the yield sequence is stationary after the first-order difference. Different yields to maturity may be cointegrated, and Equation 1 can be rewritten as follows:

$$\begin{aligned} S(n,t) &\equiv R(n,t) - R(1,t) \\ &= \frac{1}{n}\sum_{i=1}^{n-1}\sum_{j=1}^{i=j} E_t \Delta R(1,t+i) + L(n,t) \end{aligned} \qquad (2)$$

where $S(n,t)$ refers to spread when $\Delta R(n,t) = R(n,t) - R(n,t-1)$.

If $\Delta R(1,t)$ and term premium $L(n,t)$ are stationary, then spread $S(n,t) \equiv R(n,t) - R(1,t)$ is also stationary. Under these conditions, the expectation theory can be applied to explain cointegration between yield rates with different terms.

III. Testing for Asymmetry

Threshold unit root tests

Pippenger and Goering (1993), Balke and Fomby (1997), Enders and Granger (1998) and Enders and Siklos (2001) have advanced the notion that if a sequence is asymmetric, traditional unit-root tests and cointegration tests should have relatively low power. Hence, when the term structure of interest rates has asymmetrical adjustments, the application of traditional unit-root tests should likely result in signicant deviations. To test for nonlinear asymmetrical adjustments, Enders and Granger (1998) adopted the TAR model, which is expressed as follows:

$$\Delta S_t = I_t \rho_1 (S_{t-1} - \omega) + (1 - I_t)\rho_2 (S_{t-1} - \omega) + \varepsilon_t \quad (3)$$

where I_t is the Heaviside indicator function which can be expressed as follows:

$$I_t = \begin{cases} 1 & \text{if } S_{t-1} \geq \omega \\ 0 & \text{if } S_{t-1} < \omega \end{cases} \qquad (4)$$

When the time sequence makes it symmetrical, then we cannot reject the null hypothesis $\rho_1 = \rho_2$, but the threshold value is zero. On the other hand, the necessary condition for spread S_t to be stationary is $-2 \leq (\rho_1, \rho_2) < 0$. When the variant in the residual errors ε_t is large in quantity, only one ρ_i exists between -2 and 0, and the other ρ_i is zero. Even within the nonconverging unit-root area ($\rho_i = 0$), ε_t can just be transferred to a converging area. The nonlinear null hypothesis posits that the F-test has a unit root, i.e. $\rho_1 = \rho_2 = 0$. The maximum test value t of some ρ is referred to as t-Max, while the minimum test value is referred to as t-Min and the F-statistic as value ϕ. Enders and Siklos (2001) state that the necessary conditions for nonlinear regressive convergence is that ρ_1 and ρ_2 must be negative. Additionally, Tong (1983) proposed that when spread S_t is in a stationary state and when the null hypothesis of $\rho_1 = \rho_2 = 0$ is rejected, the test value F can be reused to test for the presence of symmetry ($\rho_1 = \rho_2$) in the adjustment process.

However, we have no direct information as to the special properties of the nonlinear relations in the sequence. Enders and Granger (1998) and Caner and Hansen (2001) have developed the M-TAR model. In the process of sequence adjustment (possibly dynamic), S_{t-1} is subject to variations. Equation 4 can therefore be rewritten as:

$$I_t = \begin{cases} 1 & \text{if } \Delta S_{t-1} \geq \omega \\ 0 & \text{if } \Delta S_{t-1} < \omega \end{cases} \qquad (5)$$

Enders and Granger (1998) and Enders and Siklos (2001) call this adjustment mechanism a M-TAR process, since the series exhibits more momentum in one direction than the other. Generally speaking, when positive deviations continuously surpass negative deviations, the TAR model is capable of capturing the deep process. In the case of the M-TAR model, it is the adjustment with ΔS_{t-1} taken as the threshold value for auto-regression that determines whether or not the TAR model can capture the sharp process. The M-TAR model can be employed to test for the existence of a unit root in the same way as the TAR model. Enders and Siklos (2001) rightly point out that the M-TAR model is quite good at capturing the phenomenon when the time sequence is in a sliding change, while Caner and Hansen (2001) also point out that when the time sequence is nonstationary, the M-TAR model is better at capturing asymmetrical dynamic adjustments.

Threshold cointegration

When the interest rate has a unit-root or spread S_t is in a stationary state, the cointegration model can be utilized to check whether the current trends in the interest rate will last for long. The term structure of the long-term interest rate is expressed as:

$$R(n,t) = \alpha_0 + \alpha_1 R(1,t) + \mu_t \tag{6}$$

When the residual error μ_t in Equation 6 is stationary, it is indicative of a cointegrated relationship between different interest rates. Enders and Siklos (2001) rewrite Equation 6 in the same form as:

$$\Delta\hat{\mu}_t = I_t\rho_1\hat{\mu}_{t-1} + (1 - I_t)\rho_2\hat{\mu}_{t-1} + \sum_{i=1}^{q}\beta_i\Delta\hat{\mu}_{t-i} + \varepsilon_t \tag{7}$$

where

$$I_t = \begin{cases} 1 & \text{if } \hat{\mu}_{t-1} \geq \omega \\ 0 & \text{if } \hat{\mu}_{t-1} < \omega \end{cases} \quad \text{or} \quad I_t = \begin{cases} 1 & \text{if } \Delta\hat{\mu}_{t-1} \geq \omega \\ 0 & \text{if } \Delta\hat{\mu}_{t-1} < \omega \end{cases}$$

In the cointegration equation, the test values ϕ and ϕ^* of the *F*-statistics of both the TAR and M-TAR models are used to test for cointegration among different interest rates. An inter-variable adjustment is symmetrical; that is, the null hypothesis $\rho_1 = \rho_2$ cannot be rejected. Thus, the Engle–Granger cointegration equation is a special case of Equation 7. Enders and Siklos (2001) and Enders and Dibooglu (2002) claim that the power of the asymmetrical adjustment of ϕ exceeds that of the Engle–Granger tests. When there is an increase in the asymmetrical effect, the test value ϕ is superior to the Engle–Granger tests in terms of power.

As a general rule, the threshold value ω is unknown. Chan's (1993) method can be applied to determine both the minimum value of the square terms of the residual errors and the value of the threshold value ω.[1] Enders and Siklos (2001) suggest the application of the Akaike Information Criteria (AIC) or Bayesian Information Criteria (BIC) in the selection of the TAR or M-TAR model.

IV. Reasons for Asymmetric Adjustments in Taiwan

The central bank of Taiwan is highly committed to maintaining stability in commodity prices, particularly when it is formulating monetary policy, and in this regard, Stlvester and Haan (1996) argued that, though maintaining stability in commodity prices is the principal responsibility, monetary policy can serve multiple goals. Further, the central bank considers adjustments to monetary policy for the purpose of inflation, considerably more important than those for deflation. The same is true for the central bank's attitude towards the exchange rate, and therefore, it is more willing to tolerate currency appreciation than depreciation, especially when the economic cycle is in a depression or slump. For the sake of kick-starting a stagnant economy and expanding aggregate demands, the central bank tends to create a favourable monetary climate by lowering interest rates. But, the implementation of new monetary policy does not immediately reap benefits on account of the lag effect. For this reason, the central bank usually adopts measures that have more effective and more immediate effects to offset the negative impact of an economic slowdown. Given the conditions of long-standing equilibrium, various shifts in monetary policy possibly occur, due in large part, to the central bank's expectations about trends with regard to periods of recession and inflation. Starting in the second half of 2000, the so-called 'bubble economy' plagued the entire world. And the situation was no different in Taiwan: the economy plunged into recession and all aspects of the economy performed poorly. And just as bad,

[1] Chan's (1993) method involves arranging residual error terms in order from small to large. The first and last 15% are removed, and the middle 70% are selected. The sum of squares of the residual errors is minimized before the value ω is determined.

there were overriding pessimistic expectations among government officials and market participants that the economic stagnation would persist. These factors compelled the central bank to keep lowering the discount rate in tandem with the US Federal Reserve Bank. Regardless of the seriousness of inflation, as evidenced in deflation, for the purposes of preventing the economy from worsening, the central bank was virtually relentless in pursing expansionary monetary policies (for instance, by lowering the discount rate and the required reserve ratio) by diverting funds from financial institutions to enterprises and the public. Thus, the implementation of various policies may constitute the reason for nonlinear dynamic adjustments. During the sample research period in this study, the central bank has been very flexible when it comes to adjusting its monetary policy, as is evidenced in the sharp decreases in interest rates within only 1 year. It is possible that adjustments to the term structure of interest rates triggered asymmetrical adjustments.

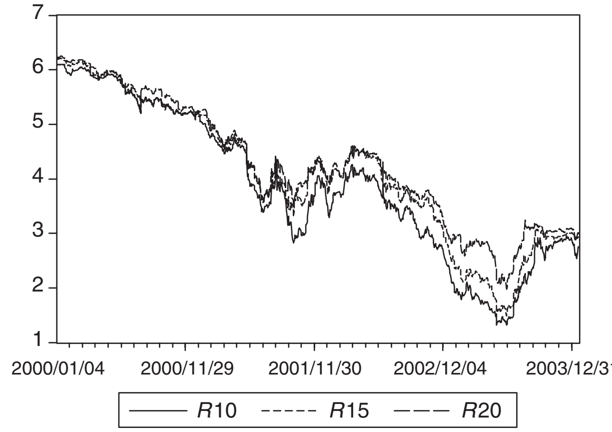

Fig. 1. Government bond yields from 2000 to 2003

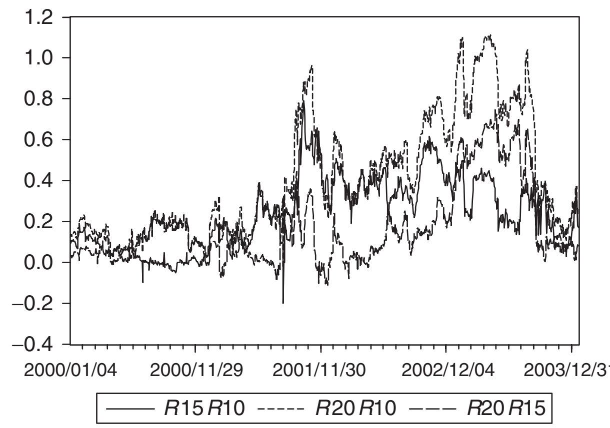

Fig. 2. Differentials between the 10-, 15- and 20-year government bond yields

V. Empirical Results

The sample data selected in the current study is information on the yield rates of Taiwan government bonds with 10-, 15- and 20-year terms. The research covers the 4-year period of 2000–2003, and the data are from Reuters and the GreTai Securities database. As much as Taiwan government bonds were still in their infancy in the early part of the 1990s, the bond market was inactive as it faced many restraints – for example, few market participants, a lack of market makers and trading activities that were mostly buy-and-holds. Nevertheless, by virtue of the installation of the electronic transaction platform for government bonds at the Over-the-Counter (OTC) in 2000, rationality and transparency in price formation in the bond market increased as a whole. This explains the fact that, as of the year 2000, the trading volume in the Taiwan bond market began to grow at an accelerated pace, and the daily volume of trade in the bond market surpassed the volume of trade on the TSE market by a comfortable margin. The representative terms for bonds in the bond market are 10, 15 and 20 years. Today, transactions in these 10-, 15- and 20-year bonds account for more than 90% of the total volume of trade in government bonds. With this in mind, in the present study, we select these three bonds as the targets to analyse adjustments to the term structure of interest rates. It is equally important that despite numerous issues, the Taiwan government bond market does not draw on re-opening mechanisms. The rapid replacement of leading government bonds with market participants has shown that investors are more inclined to discard the old in favour of the new. Thus, in selecting the government bond yield rate, we continuously replace old bonds[2] with new bonds with the same term so that the bond yield rate is the latest turnover yield in the market. In this way, price distortions resulting from the issuance of new bonds can be avoided.

Figures 1 and 2 depict the trends with respect to the yields of the three kinds of government bond and the trends in the paired spreads, respectively. In Fig. 1, it is clear that the interest rate sharply decreases starting in the year 2000. But, by mid-2002, the government bond yield begins to increase with a gradual upturn in

[2] Since mainstream bonds and dealer quotations are both active, trading volume accounts for the lion's share of all buys and sells. Other bonds of different maturities, on the other hand, are traded little, making trading volume comparatively meagre.

the economy. Figure 2, depicting the trends in the paired spreads, shows that a sharp rise in spread seems more continuous than the sharp decrease in spread. Obviously, it is feasible to adopt either the TAR or M-TAR model to estimate the adjustment of spread. We present our analysis of the empirical results in the following sections.

Unit root test results of asymmetry

To check whether spread has a unit root, the current study adopts the traditional linear Augmented Dickey–Fuller (ADF) test and the asymmetrical TAR and M-TAR unit-root tests, and the test results are given in Table 1. The first and second rows in each panel present the TAR and M-TAR test results when the threshold value is zero, while the third and fourth rows present the ADF test results. Note that the threshold value ω is generally unknown. The present study takes Chan's (1993) minimum values of the square terms of the residual errors as the threshold values. Enders and Siklos (2001) suggest applying the AIC or BIC to determine the most suitable model. As shown in Table 1, Chan's M-TAR model is the optimal method for the paired spread of the three bonds. The threshold values of the interest rates of the spread between the 15- and 20-year yield rate, 10- and 20-year yield rate and 10- and 15-year yield rate are −0.006, 0.0105 and 0.006, respectively. Regardless of whether we use the TAR or M-TAR, the null hypothesis ($\rho_1 = \rho_2 = 0$) is rejected, and the ϕ values are all significant at the 5% level. It is worth noting that the traditional linear ADF test results show the reverse. The results fail to reject the null hypothesis, signifying that spread is in a nonstationary sequence. In terms of model selection, the ADF unit-root test values of AIC and BIC are higher than those from both the TAR and M-TAR, which makes it clear that both the TAR and M-TAR models are superior to the traditional ADF model. In addition, it can clearly be seen in Fig. 1 that movements in the interest rates during these three terms are highly correlated (i.e. there is cointegration and the spread is a stationary sequence). In this study, we subscribe to the view that the unit-root test of the traditional linear hypothesis cannot capture the dynamics and asymmetric adjustments to spread. Traditional unit-root test methods and cointegration tests will lead to suffer from low power and yield results that lack consistency.

Once we confirm that spread is stationary, to check for asymmetry, we investigate spread adjustment. The second last column of Table 1 presents the *F*-test ($\rho_1 = \rho_2$) results, and clearly, both the TAR and M-TAR test results reject the null hypothesis at the 5% level of significance. To sum up, in Table 1, we note that spread is stationary and that adjustment is asymmetric.

Cointegration test results of asymmetry

Table 2 provides the cointegration test results on the term structure of interest rates. To test the validity of the null hypothesis, we test for cointegration between the rates of government bonds with different maturities within the framework of the expectation theory. We find that the M-TAR-C model with the AIC and BIC as the selection standards is superior to the M-TAR and TAR models with the threshold value of zero. Without exception, all three nonlinear asymmetric models reject the null hypothesis ($\rho_1 = \rho_2 = 0$) at the 5% level of significance, indicating that cointegration exists in the rates of long-term government bonds with different maturities. We adopt Chan's (1993) method to determine the most suitable threshold value. The threshold value of the interest between the 15- and 20-year yield rate, 10- and 20-year yield rate and 10- and 15-year yield rate are respectively −0.01144, 0.00528 and −0.00959. When we conduct the traditional linear E–G cointegration test, the null hypothesis cannot be rejected. Pertinent here, this does not lend support for the expectation theory as far as the term structure of interest rates goes. It is obvious from Fig. 1 that there is cointegration between the yield rates of government bonds with different maturities. But, the cointegration tests of the traditional linear hypothesis cannot capture the relationships among long-term bonds. On the basis of the results from both of those tests, the null hypothesis could not be rejected; in other words, there is no cointegration among those government bonds.

After confirming whether the yield rates of government bonds of different maturities are subject to nonlinear adjustment, we must determine whether adjustments are asymmetrical or not. This question can be resolved by referring to Table 3. The TAR model does not reject the null hypothesis $\rho_1 = \rho_2$, whereas the M-TAR and M-TAR-C do reject it at the 5% level of significance. Based on actual data, Fig. 1 shows that the interest rate begins to drop in 2000. The M-TAR model is able to capture the sharp data adjustment. Figure 2 shows that the spread between government bonds with different maturities is relatively stable in the early part of 2000. But, with the central bank continuing to lower all kinds of discount rates, interest rates start to fluctuate more, in turn creating wide fluctuations in spread. In the second half of 2003, the global economy began to pick up, and although the central bank still had its flexible

Table 1. Test results for a unit root in the yield spread

Model	Lag	ρ_1		ρ_2		AIC/BIC[a]	ϕ[b]	$\rho_1=\rho_2$[c]	$Q(4)$[d]
15- and 20-year yield rate									
TAR	3	−0.0062	(−1.7323)[e]	−0.2532***	(−3.6594)[f]	−145.0008/−120.4073	8.1169***	12.7261***	3.8541 (0.4261)
M-TAR	3	0.0016	(0.3060)	−0.0162***	(−2.8254)	−136.8217/−112.2282	3.9986**	4.5177**	2.9324 (0.5692)
ADF	3	−0.0667	(−1.8739)			−135.5390/−115.8570			2.8285 (0.5870)
M-TAR-C[g] ($\omega=-0.006$)	3	0.0055	(1.1536)	−0.0284***	(−4.2852)	−147.3721/−122.7787	9.3171***	15.1184***	3.3462 (0.5017)
10- and 20-year yield rate									
TAR	1	−0.0028	(−1.2460)	−12.0404***	(−9.5911)	371.5835/386.3455	46.6405***	91.2698***	2.9456 (0.5670)
M-TAR	1	0.0085***	(2.4007)	−0.9600***	(−4.0536)	355.9690/370.7311	9.5237***	17.8048***	2.7114 (0.6072)
ADF	1	−0.0028	(−1.1837)			375.0354/394.7181			3.6181 (0.4600)
M-TAR-C ($\omega=0.0105$)	1	0.0147***	(3.3929)	−0.0130***	(−4.0561)	351.2924/366.0544	11.9046***	22.5608***	3.4003 (0.4932)
10- and 15-year yield rate									
TAR	3	−0.0052	(−1.4688)	−0.6787***	(−5.5703)	138.9869/163.5803	16.4725***	30.5516***	1.3552 (0.8519)
M-TAR	3	−0.0131***	(−2.3976)	−0.0261***	(−4.4961)	139.0443/163.6377	11.3305***	20.2912***	2.7460 (0.6012)
ADF	3	−0.006	(−1.6837)			142.4780/162.1607			3.1941 (0.5260)
M-TAR-C ($\omega=0.006$)	3	0.0202***	(3.1658)	−0.0227***	(−4.5205)	135.6527/160.2462	13.0588***	23.7398***	3.4656 (0.4813)

Notes: [a]$AIC = T*\ln(RSS) + 2*n$; and $BIC = T*\ln(RSS) + n*\ln(T)$, where n = number of regressors and T = number of usable observations. RSS is the Residual Sum of Squares.
[b]Entries in this column are sample F-statistics from testing the null of $\rho_1=\rho_2=0$. This test follows a nonstandard distribution; the test statistics are compared with the critical values reported by Enders and Siklos (2001).
[c]Entries in this column are sample F-statistics for the null hypothesis that adjustments are symmetric. The critical values are reported by Enders and Siklos (2001).
[d]$Q(4)$ is the Ljung–Box Q-statistic for the joint hypothesis of no serial correlation among the first residuals.
[e]Entries in brackets in this column are the t-statistics for the null hypothesis $\rho_1=0$. Critical values are taken from Enders and Granger (1998).
[f]Entries in brackets in this column are the t-statistics for the null hypothesis $\rho_2=0$. Critical values are taken from Enders and Granger (1998).
[g]C denotes the model estimations using a consistent threshold estimate.
*** and ** indicate significance at the 0.01 and 0.05 levels, respectively.

Table 2. Test results for cointegration of the interest rates

Model	Lag	ρ_1		ρ_2		AIC/BIC[a]	ϕ[b]	$\rho_1=\rho_2$[c]	$Q(4)$[d]
15- and 20-year yield rate									
TAR	3	−0.0221***	(−2.5370)[e]	−0.0172**	(−1.9172)[f]	−266.4757/−241.8822	4.9792**	0.1565	2.6222 (0.6229)
M-TAR	3	−0.0077	(−0.8811)	−0.0320***	(−3.6110)	−270.2111/−245.6176	6.8596***	3.8809**	2.6618 (0.6159)
E-G	3	−0.0221	(−3.5233)			−272.8171/−253.1305			2.3339 (0.675)
M-TAR-C[g] ($\omega=-0.01144$)	3	−0.0048	(−0.6598)	−0.0584***	(−4.9800)	−281.4876/−256.8941	12.5783***	15.2080***	2.7071 (0.6080)
10- and 20-year yield rate									
TAR	0	−0.0226**	(−2.3357)	−0.0157*	(−1.8275)	102.1033/111.9466	4.3976**	0.2879	2.7339 (0.6033)
M-TAR	0	−0.0014	(−0.1581)	−0.0367***	(−4.0228)	94.7663/104.6096	8.1041***	7.6390***	1.8473 (0.7638)
E-G	0	−0.0232	(−3.6313)			95.7829/100.7046			2.8808 (0.5780)
M-TAR-C ($\omega=0.00528$)	0	0.0073	(0.7410)	−0.0367***	(−4.4814)	90.4128/100.2561	10.3161***	12.0261***	1.7387 (0.7837)
10- and 15-year yield rate									
TAR	3	−0.0176*	(−1.7840)	−0.0304***	(−2.7683)	38.6585/63.2520	5.3306***	0.7712	2.4107 (0.6607)
M-TAR	3	0.0012	(0.1172)	−0.0475***	(−4.6034)	28.2121/52.8056	10.6103***	11.2280***	1.8925 (0.7555)
E-G	3	−0.0236	(−3.2137)			23.4666/49.1532			2.7806 (0.5950)
M-TAR-C ($\omega=-0.00959$)	3	−0.0029	(−0.3220)	−0.0631***	(−5.0490)	23.9556/48.5491	12.7723***	15.5196***	2.2731 (0.6857)

Notes: [a]AIC $= T*\ln(\text{RSS})+2*n$; and BIC $= T*\ln(\text{RSS})+n*\ln(T)$, where n = number of regressors and T = number of usable observations. RSS is the Residual Sum of Squares.

[b]Entries in this column are sample F-statistics for testing the null of $\rho_1=\rho_2=0$. This test follows a nonstandard distribution; thus, the test statistics are compared with critical values taken from by Enders and Siklos (2001).

[c]Entries in this column are sample F-statistics for the null hypothesis that adjustments are symmetric. The critical values are taken from Enders and Siklos (2001).

[d]$Q(4)$ is the Ljung–Box Q-statistic for the joint hypothesis of no serial correlation among the first residuals.

[e]Entries in brackets in this column are the t-statistics for the null hypothesis $\rho_1=0$. Critical values are taken from Enders and Granger (1998).

[f]Entries in brackets in this column are the t-statistics for the null hypothesis $\rho_2=0$. Critical values are taken from Enders and Granger (1998).

[g]C denotes the model estimations using a consistent threshold estimate.

***, ** and * indicate significance at the 0.01, 0.05 and 0.1 levels, respectively.

Table 3. Estimated asymmetric error-correction models for term spread

	$\Delta R10$	$\Delta R20$	$\Delta R10$	$\Delta R15$
C^{a}	−0.0030 (−1.7620)*	−0.0031 (−2.1809)**	−0.0026 (−1.4983)	−0.0029 (−1.8795)*
$\Delta R10$ (−1)	−0.0782 (−1.6971)*	−0.0403 (−1.0624)	−0.0913 (−1.7551)*	−0.0168 (−0.3625)
$\Delta R10$ (−2)	0.1478 (3.1915)***	0.1012 (2.6523)***	0.1457 (2.7989)***	0.1376 (2.9558)***
$\Delta R10$ (−3)	−0.1099 (−2.3645)**	−0.1179 (−3.0820)***	−0.1321 (−2.5368)**	−0.0344 (−0.7347)
$\Delta R10$ (−4)	0.1434 (3.008)***	0.1081 (2.8111)***	0.0700 (1.3346)	0.1235 (2.6281)***
$\Delta R20$ (−1)	0.1537 (2.7452)***	0.1360 (2.9510)***	0.1371 (2.3748)**	0.0648 (1.2558)
$\Delta R20$ (−2)	−0.2004 (−3.5709)***	−0.1150 (−2.4840)**	−0.1545 (−2.6569)***	−0.1433 (−2.7627)***
$\Delta R20$ (−3)	0.0745 (1.3221)	0.0609 (1.3126)	0.0957 (1.6533)*	−0.0027 (−0.0512)
$\Delta R20$ (−4)	0.1153 (−1.0418)**	−0.0839 (−1.8061)*	−0.0096 (−0.1592)	−0.0655 (−1.2569)
γ_1	−0.0264 (−1.9147)*	0.0081 (0.5961)	−0.0318 (−2.2592)**	−0.0219 (−1.5736)
γ_2	−0.0036 (−0.3064)	−0.0207 (−1.7962)*	0.0237 (1.1497)	0.0142 (0.7357)
$\mathrm{H}_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$		7.3891***		4.5132***
$\mathrm{H}_0: \theta_1 = \theta_2 = \theta_3 = \theta_4 = 0$	6.3303***		4.0484***	
$\mathrm{H}_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \gamma_1 = 0$		5.9323***		4.4151***
$\mathrm{H}_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \gamma_2 = 0$		6.4791***		3.7022***
$\mathrm{H}_0: \theta_1 = \theta_2 = \theta_3 = \theta_4 = \gamma_1 = 0$	5.9819***		4.4149***	
$\mathrm{H}_0: \theta_1 = \theta_2 = \theta_3 = \theta_4 = \gamma_2 = 0$	5.0657***		3.5065***	
R10 $\mathrm{H}_0: \gamma_1 = \gamma_2$	19.6229***			
R20 $\mathrm{H}_0: \gamma_1 = \gamma_2$		14.5081***		
R10 $\mathrm{H}_0: \gamma_1 = \gamma_2$			13.4018***	
R15 $\mathrm{H}_0: \gamma_1 = \gamma_2$				8.4452***
Q (4)	0.0309	0.1775	0.0627	0.0504

	ΔR15	ΔR20
C^{b}	−0.0035 (−2.2307)**	−0.0035 (−2.4438)**
ΔR15 (−1)	0.0068 (0.1251)	0.0338 (0.6890)
ΔR15 (−2)	0.0228 (0.4242)	0.0220 (0.4483)
ΔR20 (−1)	0.0597 (1.0179)	0.0523 (0.9762)
ΔR20 (−2)	−0.0622 (1.0656)	−0.0382 (−0.7147)
γ_1	0.0039 (0.3305)	0.0142 (1.1785)
γ_2	−0.0437 (−2.3051)**	−0.0739 (−3.8315)***
$\mathrm{H}_0: \delta_1 = \delta_2 = 0$		0.3217
$\mathrm{H}_0: \theta_1 = \theta_2 = 0$	1.1115	
$\mathrm{H}_0: \delta_1 = \delta_2 = \gamma_1 = 0$		0.6136
$\mathrm{H}_0: \delta_1 = \delta_2 = \gamma_2 = 0$		5.2695***
$\mathrm{H}_0: \theta_1 = \theta_2 = \gamma_1 = 0$	0.7852	
$\mathrm{H}_0: \theta_1 = \theta_2 = \gamma_2 = 0$	2.6143**	
R15 $\mathrm{H}_0: \gamma_1 = \gamma_2$	4.5300**	
R20 $\mathrm{H}_0: \gamma_1 = \gamma_2$		15.0503***
Q (4)	2.5441	1.8782

Notes: Threshold error-correction model:

$$\Delta R_{it} = \gamma_1 Z^{+}_{t-1} + \gamma_2 Z^{-}_{t-1} + \sum_{i=1}^{k_i} \theta_i \Delta R_{1t-i} + \sum_{i=1}^{k_t} \delta_i \Delta R_{2t-i} + \nu_t$$

where R_{it} is term yield; $Z^{+}_{t-1} = I_t \hat{\mu}_{t-1}$; $Z^{-}_{t-1} = (1 - I_t)\hat{\mu}_{t-1}$ such that $I_t = 1$ if $\mu_{t-1} \geq \omega$, $I_t = 0$ if $\mu_{t-1} \leq \omega$; and ν_t is a white-noise disturbance. Lag-length selection is based on the AIC. The t-statistics are in parentheses.

[a]Threshold ω is 0.00528 in the 10- and 20-year error-correction model and −0.00959 in the 10- and 15-year error-correction model.

[b]The threshold ω is −0.01144 in the 15- and 20-year error-correction model.

***, ** and * indicate significance at the 0.01, 0.05 and 0.1 levels, respectively. The t-statistics are in parentheses.

monetary policies in place, the market as a whole expected the central bank to raise interest rates. And just as the interest rates and government bonds were starting to rebound, the fluctuations in the interest rates diminished. We are able to employ the M-TAR model for the period with the wide fluctuations in the interest rates to capture the dynamics of the adjustment of the term structure of interest rates.

Threshold Error-Correction Model (TECM)

When there is threshold asymmetric adjustment cointegration among interest rates, we can apply the TECM to determine the short-term dynamics and long-term balanced relations in the term structures of the interest rates. The error-correction model for threshold asymmetry is written as follows (Enders and Granger, 1998; Enders and Siklos, 2001):

$$\Delta R_{it} = \gamma_1 Z^+_{t-1} + \gamma_2 Z^-_{t-1} + \sum_{i=1}^{k_i} \theta_i \Delta R_{1t-i} + \sum_{i=1}^{k_2} \delta_i \Delta R_{2t-i} + \nu_t \tag{8}$$

where R_{it} refers to bond yield; $Z^+_{t-1} = I_t \hat{\mu}_{t-1}$ and $Z^-_{t-1} = (1 - I_t)\hat{\mu}_{t-1}$ when μ_{t-1} is greater than or equal to the threshold value, $I_t = 1$. But, when μ_{t-1} is lesser than the threshold value, $I_t = 0$, and ν_t is the interference item of white noise. The model is selected in accordance with the results of the AIC and BIC. In Table 2, we note that Chan's (1993) M-TAR-C model results are optimal. The current study, therefore, adopts the M-TAR-C error-correction model to estimate the short- and long-term balanced relationships among bonds with different maturities, and we employ the Granger-causality tests to discriminate between $\Delta R_{1,\,t-i}$ and $\Delta R_{2,\,t-i}$.

Table 3 shows that adjustments to the long-term balanced interest rates are asymmetric (i.e. the null hypothesis of $H_0: \gamma_1 = \gamma_2$ is rejected) and the differences in the yield rates of the three long-term government bonds are significant at the 1% level. On the other hand, as regards the relationship between the short-term yield rates, we find bi-directional causality between the 10- and 20-year yield rate as well as between the 10- and 15-year yield rate. That is to say, the null hypotheses $H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$ and $H_0: \theta_1 = \theta_2 = \theta_3 = \theta_4 = 0$ are rejected. But the null hypotheses $H_0: \delta_1 = \delta_2 = 0$ and $H_0: \theta_1 = \theta_2 = 0$ cannot be rejected for the relationship between the 15- and 20-year yield rate, which signifies that there is no causal relationship between the two bonds. And the reason is simple: although the three bonds are mainly traded in the Taiwan bond market, the most popular is the 10-year bond, and given its shorter duration, traders face less risk[3] when the same unit interest rate fluctuates. Noteworthy, this indicates that the 10-year bond is highly commonly-traded in the market and, in fact, that it serves as the leading indicator of fluctuations in the yield rates in the government bond market. Since bonds with other maturities vary with adjustment to the 10-year government bond, this bond bears a close relation to the short-term balanced adjustment to the 15- and the 20-year government bonds. In the long-term balanced relationships, we find that in the process of interest rate adjustment, either upward or downward adjustments to the threshold values of the 10-, 15- and 20-year government bonds rejects the null hypothesis and is significant at the 1% level. In other words, 10-, 15- and 20-year government bonds are closely related in terms of long-term balanced adjustments. As for the 20- and 15-year bonds, there is no evidence of the feedback effect unless the interest rate fluctuates below the threshold value ($\omega = -0.01144$). Therefore, fluctuations in the interest rates of the two bonds higher than the threshold values fail to exhibit the price feedback effect. When the balanced relationships between the 10-, 15- and 20-year government bonds are combined, the 10-year bond generates the price transmission effect on the 15- and 20-year government bonds in the long run, while the 20- and 15-year bonds do not exert the price transmission effect in the short run. Only with long-term equilibrium and when fluctuations in the interest rate are less than the threshold value, is the transmission effect exerted.

Table 3 also shows that similar to the factors involved in adjustment between the yield rates of government bonds, $\gamma_1(Z^+_{t-1})$ and $\gamma_2(Z^-_{t-1})$, for adjustment between interest rates appears to be asymmetric. Between the 15- and the 20-year government bonds, the downward adjustment of the interest rate is greater than the upward adjustment; that is, when there is long-term equilibrium, a decrease in the yield rate is greater than an increase. In Table 3, we also note that when the interest rate decreases, the factors for the adjustment of the 15- and 20-year bonds have

[3] Price fluctuations in the bond market are expressed in terms of duration: $\Delta P = -P * \Delta R * MD$, where P refers to bond price; ΔR is fluctuation in the interest rate; and MD is modified duration which is duration/$1 + R$. It is hypothesized that when the price of bonds with different maturities changes in the same way as the interest rate, the changes in bond price are related to duration. Simply, the longer the duration of a bond, the greater are the changes in profits and losses as a result of the fluctuations in the unit interest rate.

a significant effect but that when interest rates rise, those same factors do not have any significant effect. Furthermore, when 15- and 20-year bonds are at the threshold value, they have a significant effect on 10-year bonds. When 10-year bonds are below the threshold value, they have a significant effect on 15- and 20-year bonds. This can be attributed to the fact that when interest rates go down, the 10-year government bonds respond first, causing the price transmission effect to come into play. This stimulates interest in the longer 15- and 20-year government bonds. By contrast, when the expected interest rate is on the increase, 15- and 20-year government bonds are sold first in the market for the purpose of reducing losses from longer duration. The 10-year bonds with shorter duration are subsequently sold, illustrating that adjustments to the yield rate of government bonds are asymmetrical.

As far as investors and traders are concerned, they are urged to keep themselves informed of the M-TAR model results and use relative changes in the yield rates of bonds with different maturities to adjust the contents of their investment portfolios. Changes in the long- and short-term yield rates affect the shape of the yield curve. And, if an increase in the yield rate of 20-year bonds is expected to surpass the threshold value (0.00528) of 10-year bonds (i.e. the gradient of the yield curve is expected to become sharper), then the share of 10-year bonds in an investment portfolio should be augmented, while that of 20-year bonds should be reduced.[4] Following the same rationale, if an increase in the yield rate of 15-year bonds is expected to be less than the threshold value (−0.00959) of 10-year bonds (i.e. the gradient of the yield curve grows more slowly), the share of 10-year bonds in an investment portfolio should be augmented, while that of 15-year bonds should be reduced. The same principle applies to investment portfolios with 15- and 20-year bonds. It is important to continuously be prepared to effectively adjust portfolios.

VI. Conclusions

The present study analyses adjustments to the term structure of the interest rates of long-term government bonds in the Taiwan bond market. We adopt the asymmetrical TAR and M-TAR unit-root and cointegration tests, developed by Enders and Granger (1998) and Enders and Siklos (2001), and we employ the nonlinear method to test whether the term structure of interest rates supports the expectation hypothesis. But in fact, it departs from the traditional expectation hypothesis which postulates that spreads with different interest rates remain fixed. The empirical results, however, do provide evidence that Taiwan's term structure of long-term interest rates is highly consistent with expectation theory, according to which spreads are subject to dynamic and asymmetric adjustments. We analyse 10-, 15- and 20-year government bonds in Taiwan, and based on the empirical results, it is clearly apparent that when interest rates rise or fall, the 10-year government bonds exhibit the price transmission effect on the 15- and 20-year government bonds. It is also clear that spread is subject to asymmetric dynamic adjustments in both the short- and long-run. On the other hand, when interest rates drop, the 15- and 20-year government bonds exhibit the price transmission effect. The transmission effect of the 15- and 20-year government bonds is insignificant when interest rates rise. Thus, there is no question that the asymmetrical error-correction model can effectively be applied to capture dynamic adjustments of interest rates.

[4] The share of long-term bonds can be adjusted by using a duration matching analysis as follows: suppose the investment portfolio consists of two kinds of government bonds with different maturities; x refers to the share of government bonds with the first maturity, and D_1 and D_2 refer to the durations of these two kinds of bonds. D_p, the duration of the investment portfolio, is: $xD_1 + (1-x)D_2 = D_p$, and the holding share $x = (D_2 - D_p)/(D_2 - D_1)$. If the interest rate sensitivity of an investment portfolio is measured on the basis of duration, when the threshold value is exceeded, the duration of the investment portfolio should be adjusted in terms of the share of each bond in the investment portfolio. In addition, if the risk of the bonds in an investment portfolio is considered, then variance matching should be applied to determine the optimum holding proportion. Suppose σ_1 and σ_2 individually represent the risk of two bonds (measured by undulatory properties). ρ refers to the coefficient of the relation between the two kinds of bonds; then the variance in an investment portfolio is: $V(R_P) = x^2\sigma_1^2 + (1-x)^2\sigma_2^2 + 2x(1-x)\rho\sigma_1\sigma_2$. When the threshold value is modified and risk is taken into account, we can solve the most appropriate ratio of the bond investment portfolio. Primary differentiation of $V(R_P)$ and holding proportion x are zero. The most appropriate ratio of government bonds can be calculated as follows:

$$x = \frac{\sigma_2^2 - \rho\sigma_1\sigma_2}{\sigma_1^2 + \sigma_2^2 - 2\rho\sigma_1\sigma_2}$$

when a variation in the yield rate exceeds the threshold value, the two aforementioned methods, should be adopted to determine the most appropriate investment portfolio.

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